NOTES ON THE STRUCTURAL RELATIONS OF AUSTRALASIA, NEW GUINEA, AND NEW ZEALAND

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INTRODUCTION

The accompanying brief note is an attempt at the co-ordination of our increasing knowledge of the structural development of Australia and the neighboring islands.

The ideas given in this note are intended only as a temporary viewpoint from which to consider the work of the great pioneers of geology in Australia and as an inference or tentative hypothesis to stimulate interest in those magnificent field problems in Australasia, New Guinea, New Caledonia, and New Zealand, which call so urgently for solution. In this way it is hoped that the scheme here proposed will serve as a rough clue to the unraveling of certain vexed questions in the stratigraphic and structural history of Australia.

Several difficult points need explanation before any simple account of the building of Australia would be possible. Thus in the discussion of the Devonian it must not be forgotten that folds supposed to be of this age occur in *Northwest* Australia. Highly altered rocks of unknown age and of large area occur also in Northern and Northeastern Queensland, and the occurrence of these has not been explained in the present note. Then again, it must not be forgotten that our knowledge of some of the Permo-Carboniferous rocks, such as the Gympie of the Queensland geologists, is far from satisfactory.

Again, it is not known how many of the observations of the older workers in connection with the strike of folds were merely local and how many were conducted on a large scale.

Acknowledgments.—The writer is deeply indebted to Professor Leo A. Cotton and Dr. W. N. Benson, of Sydney University, for their kindness in reading the report in manuscript and for supplying additional information as to literature on the pre-Cambrian and Ordovician, and for kindly criticism of the notes on the Devonian, the Permo-Carboniferous and the Trias-Jura.

Previous workers.—It is the desire of the writer at this stage of our scientific development in Australia to draw attention to the work of the pioneers of geology in the great island continent. Australian pioneer geologists, in common with Australian explorers and miners, and in common also with American pioneers, have breathed the inspiration of their own mighty surroundings. Foremost among the pathfinders of geology in the country under consideration—men who crossed trackless wastes and endured untold discomforts in their pursuit of knowledge—were W. B. Clarke, R. Daintree, and A. R. C. Selwyn; others who followed in the track of these giants, but who nevertheless bore much of the heat and burden of the day and were either worthy successors or contemporaries of the pioneer trio, were H. Y. L. Brown, J. E. Carne, T. W. E. David, W. Howchin, R. Logan Jack, A. Gibb Maitland, R. Murray, S. Stutchbury, R. Tate, W. H. Twelvetrees, and C. S. Wilkinson. Among them also must be named the paleontologist, R. Etheridge, Jr., whose labors in the cause of Australian paleontology have done so much to simplify the task of the field workers. A whole group of younger enthusiasts have built and are today building on the work laid down by these pioneers.

PREVIOUS WORK DONE AND SCOPE OF PRESENT NOTE

The earliest definite statement known to the writer concerning the building of Australia as a whole was made by T. W. E. David.[1] In this detailed account Professor David's descriptions imply

[1] Presidential address on "The Growth of Australia," *Proc. Linn. Soc. N. S. Wales*, 1893, pp. 547–607.

the growth of Australia as from west to east. In 1911 the same writer amplified his earlier statement and said:[1] "Since the close of Paleozoic time Australia has been subjected to broad warps, but not to true folding except in the direction of New Guinea, where Cretaceous, and even early Tertiary, strata are highly folded. New Guinea is thus a new fold region; and even in Australia tectonic movements are newer as New Guinea is approached" (p. 59).

H. I. Jensen[2] also, in a later note, discussed the gradual growth of the eastern portion of the continent.

Like David's earlier reports, this paper of Jensen's is important and suggestive. Jensen approaches the problem of Eastern Australian history also from the viewpoint of "petrological unity." He, however, considered that the folding of the Permo-Carboniferous sediments was sporadic and had died out practically in Northern New South Wales.

In 1914 David[3] presented an epitome of Australasian geology. In this he said: "The latest folding to which the earth's crust in Australia has been subjected belongs to late Carboniferous time" (p. 256). He qualified this, however, by the statement: "The strata in the Permo-Carboniferous system are either perfectly horizontal or disposed in broad open troughs and arches. Only in the case of the strata of Drake and Undercliffe in New England and the Ashford areas [New South Wales] and the Gympie area in Queensland, are the strata of this system highly disturbed near granite intrusions" (p. 267).

The reader is referred for a consideration of this statement to the discussion of the field evidence in connection with the Permo-Carboniferous. It will then be seen how incomplete is our knowledge of the age of the sediments of Eastern Australia lying to the north of Sydney, and hence how great the need for caution to be exercised in coming to any definite conclusion as to the scheme of structure.

[1] T. W. Edgeworth David, "Presidential Address," *Proc. Roy. Soc. N.S. Wales*, 1911, pp. 15–76.

[2] "The Building of Eastern Australia," *Proc. Roy. Soc. Queensland*, July, 1911, pp. 149–98.

[3] T. W. Edgeworth David, "The Geology of the Commonwealth" (Federal Handbook), *Brit. Assoc. Adv. Sci.*, Australian meeting, 1914, pp. 241–325.

Origin and scope of present note.—The idea of writing a paper similar to the present one was conceived as far back as 1905–6, when the writer was surveying an area of folded sediments in Northern New South Wales. Previous workers had considered these beds as belonging to the older Paleozoic because they were strongly folded, whereas the beds of known Permo-Carboniferous type in Australia at that time were either horizontally bedded or only moderately domed.

David, however, in connection with these beds, had pointed out as far back as 1893: "I have, however, lately come to the conclusion that the whole of the Paleozoic sedimentary rocks of the Vegetable Creek district, provisionally classed by me as Upper Silurian or Devonian, are referable to the Gympie horizon"[1] [presumably Carboniferous.—E. C. A.].

During the progress of the survey these beds were discovered to contain many characteristic Lower Marine (Permo-Carboniferous) fossils, as probably also some Upper Marine types. The area of these Permo-Carboniferous types was proved to extend far to the north and west afterward by the field work of Carne and the writer.[2]

In Southern Queensland, near Warwick, these two observers found Lower Marine rocks folded in the most complicated manner,[3] while in 1908 during a visit to Mount Morgan, about 500 miles north of the New South Wales border, they saw rocks indicated on the Queensland geological map[4] as of the same age as the Warwick types, also highly folded.

In 1901 Mr. C. Hedley and the writer traced rocks at intervals from a little north of Townsville to near Cooktown, all highly contorted, and all shown on the Queensland geological map as of the same age as the Warwick beds. This caused the writer to consider

[1] "Presidential Address," *Proc. Linn. Soc. N.S. Wales*, 1893, pp. 586–87.

[2] J. E. Carne, "The Tin-Mining Industry of New South Wales," *Mineral Resources No. 14, Dept. Mines, Sydney, N.S.W.*, 1911, pp. 54, 70, 71; E. C. Andrews, "The Drake Copper and Gold Field, N.S. Wales," *Mineral Resources No. 12, Dept. Mines, Sydney, N.S.W.*, 1908, pp. 3–11.

[3] Drake Report. See plate opposite p. 10.

[4] R. L. Jack and R. Etheridge, *Geology of Queensland*, Brisbane (by Authority), 1892, plate 69.

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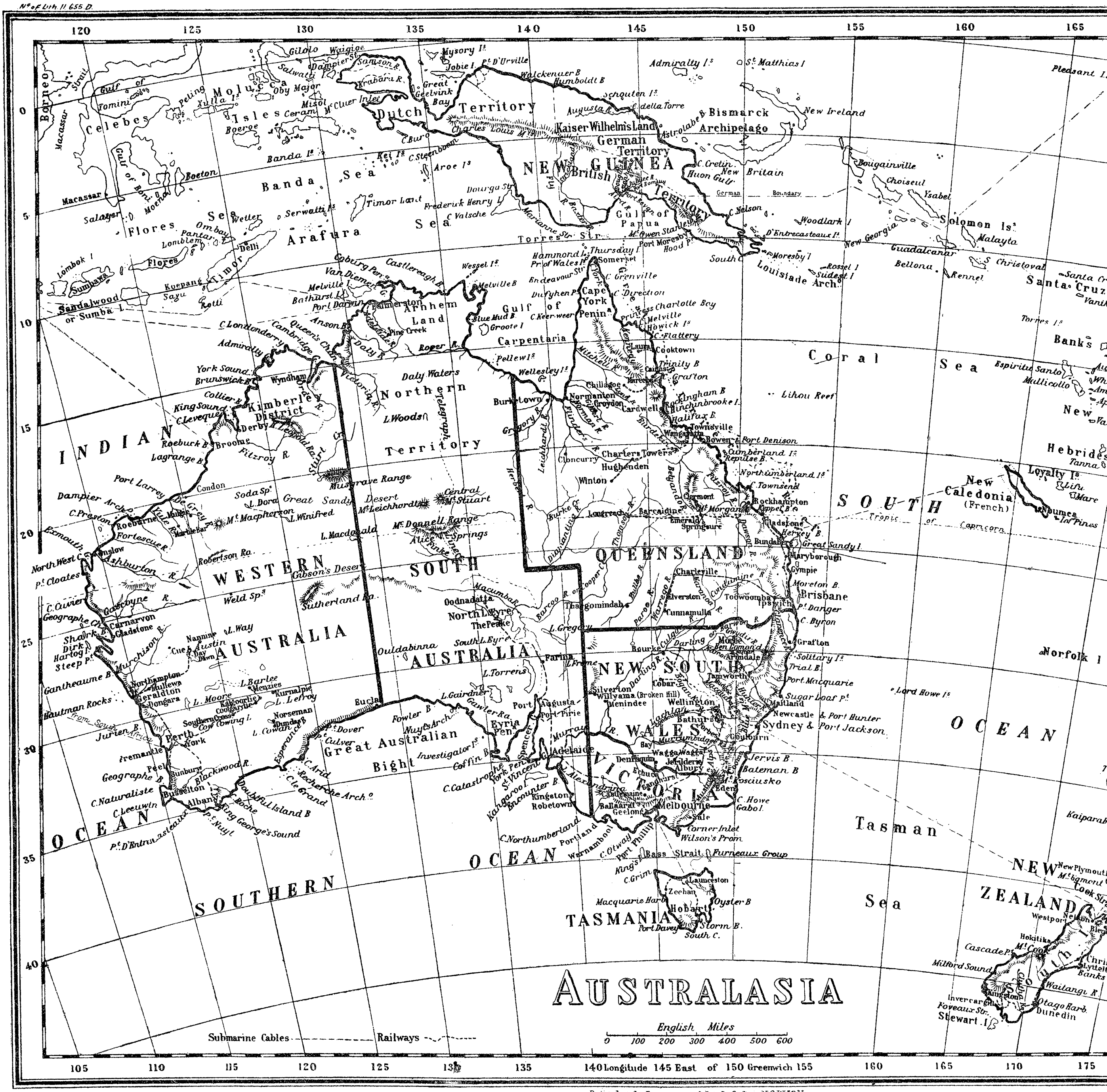

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the significance of the peculiar problem of the Permo-Carboniferous, inasmuch as the whole of the work of the field officers of the geological survey of New South Wales had proved that the Permo-Carboniferous strata south of the Hunter River (lat. 33° S.) lie almost horizontally.

The independent testimony of the ore deposits of New Zealand and Australasia was then examined, and the problem of Australasian growth was formulated in the following terms:

During the progress of geological time folding movements in Australasia retreated north and east, while ore deposition moved parallel with these movements.

The growth of New Zealand does not appear to be known definitely, but the New Guinea and the New Caledonian movements appear to have opposed the Australian direction of growth.

A study both of structure and of ore deposits suggests that New Zealand, Australia, and New Guinea have had independent origins.

GROWTH OF AUSTRALASIA FROM PRE-CAMBRIAN TO RECENT TIME

Pre-Cambrian.—The greater portion of Australia, which stretches to the west of a line drawn from the southwest of Tasmania to the center of North Queensland,[1] is composed of pre-Cambrian schists, gneisses, granites, and allied rock types. The dominant strike of the foliations is northwest and southeast, approximately, with a marked tendency to show large local, or even regional, corrugations in the eastern portion of the area. This is well shown on David's map accompanying his report of 1911[2] to the Royal Society. It is possible that at the close of the pre-Cambrian period in Australia the land surface extended across the southeastern or even the eastern portion of the continent. This is suggested, not only by the schists of Cloncurry in Northern Queensland mentioned by Woolnough, but also by the presence of great masses of schists and gneisses of unknown age in Eastern Victoria extending northward into the Cooma district.

[1] W. G. Woolnough, *Bulletin of the Northern Territory*, No. 4, Dept. External Affairs, Melbourne, 1912, p. 51.

[2] "Presidential Address," *Proc. Roy. Soc. N.S. Wales*, 1911. See large map accompanying the paper.

Browne,[1] however, inclines to the belief that a portion of this area, at least, is of Ordovician age. Other schist masses exist in Queensland.

The possibility of sediments and other rock masses being molded onto, or being wrapped round, these resistant blocks is thus suggested.

Cambro-Ordovician.—Since the momentous pre-Cambrian period the greater portion of the area mentioned appears to have been a positive or buoyant element till the present day. A great negative area appears to have existed at this time over Eastern Tasmania, Victoria, and New South Wales. It is possible, however, that a positive element existed in this period in Southeastern Victoria and New South Wales. The Cambrian sediments are more in evidence on the western strip of this area, while the Ordovician are common on the southeastern and eastern portions. It is possible that the Ordovician sediments of the more eastern areas are conformable to the Cambrian, but there is an unconformity between the shallow water forms of the two in the MacDonnell Ranges of Central Australia.

Silurian.—At the close of the Ordovician there was a very powerful folding movement. Wherever the Ordovician occurs in New South Wales or Victoria, it is strongly folded and altered. The new land surface was carried far to the north and east by this folding movement. Ordovician sediments occur quite near the coast about 100 miles south of Sydney, and they outcrop within 120 miles (lat. 33° S.) of Sydney in a direction west-northwest. Thence to the pre-Cambrian outcrops of the more western areas they may be seen in many places, exposed by the stripping of their Devonian cappings.[2] In the majority of the localities observed the strike of the sediments is west of north.

During the Silurian the old negative area which had been occupied by the Cambro-Ordovician sediments once more sank, and the sea transgressed far to the west, almost to Broken Hill (long. 141°

[1] W. R. Browne, "The Geology of the Cooma District, N.S. Wales," *Jour. Proc. Roy. Soc. N.S. Wales*, XLVIII (1914), 172–222.

[2] E. C. Andrews, "The Canbelego Gold and Copper Field," *Mineral Resources, No. 18, Dept. Mines, N.S. Wales*, 1913. See maps and sections.

E.), not nearly so far west, nevertheless, as the Ordovician sea had transgressed. This sea was shallow in places and full of islands. As in the Cambro-Ordovician period, sandy sediments and conglomerates also were deposited in the west, while great areas of coralline limestone were deposited in the eastern portions. Much of the area colored on the geological map as Devonian in the west of New South Wales may be found hereafter to be Silurian or Cambro-Ordovician in age. No fossils have been found in these beds, and they have been referred to the Devonian because of their lithological resemblance to the eastern Devonian quartzites and sandstones. The strikes of the sediments are similar to those of the Ordovician.

Devonian.—A strong movement of folding closed the Silurian and ushered in the Devonian sedimentation. The Devonian problem in Australia is complicated much in the same way as are the Carboniferous, the Permo-Carboniferous, the Trias-Jura, and the Tertiary. The work of the pioneer geologists suggested that there were two, if not three, divisions in the Devonian period, with an unconformity between two of the sets of sediment.

Mr. W. S. Dun has made a study of the Devonian in Australia and he has supplied the following notes for this report. He states that the Buchan and Bindi sediments in Victoria appear to be of Middle Devonian age, and that they are the equivalents, in great measure, of the Murrumbidgee beds in Southern New South Wales, the two groups containing types of fossils in common. In this case, however, Mr. Dun points out that it is probable that after detailed examination, Lower Devonian sediments would be found developed in these regions passing into Middle Devonian.

The Upper Devonian series of sediments are characterized by the forms *Lepidodendron australe*, *Spirifer disjuncta*, and *Rhynchonella pleurodon*. The Upper Devonian series occur both at Mount Lambie and at Tamworth (New England). In the latter locality, however, *Spirifer disjuncta* and *Rhynchonella pleurodon* do not appear to have been found.

Sussmilch,[1] in dealing with the Devonian, says: "An alternative explanation of the relations between the Lower and Upper Devonian

[1] C. A. Sussmilch, *Geology of New South Wales*, 1914, pp. 77–80.

formations, however, suggests itself, and that is that the two formations were deposited more or less contemporaneously, the former in an open but comparatively shallow continental sea, at some distance from a shoreline; the latter in the shallow coastal waters of the same sea" (p. 80). He suggests that the marked differences so well established by R. Etheridge, T. W. E. David, and W. S. Dun between the faunas of the two formations would be due in such case to the unlike environments.

To Benson's field work, however, we are indebted for one definite piece of knowledge which may be expected to help in clearing up the tangle which has gathered round the Devonian in Eastern Australia. He[1] showed that the Carboniferous in New England is actually conformable with the Devonian in that region, the sediments of each age being strongly folded, the strike of the folding being north-northwest approximately, as traced for 200 miles at least.

During various geological surveys in the western, southern, and northern parts of New South Wales, the writer has noted that the Devonian sediments vary in appearance and structure, and the results of those observations would suggest that in very great measure the Devonian sea transgressed the area of folded Silurian sediments as far west as the Darling, without extending, however, as far in that direction as had the Silurian sea. A movement of folding apparently occurred in the Devonian which affected the eastern portions of Southern New South Wales strongly, being more marked as a whole in the northern portion of that area than in the southern, and more marked in the east than in the west. This movement may have been revived still later, with a tendency to cause Australia to grow northward and eastward as it had at the close of both the Silurian and Ordovician periods, the movement of sea transgression to the west and south being less during each succeeding period.

This brings us to a mention of the long zone of weakness extending from a point somewhat south of Sydney to Queensland in a direction slightly west of north. The great negative area which had received the Ordovician and Silurian sediments had been changed to a positive element with the close of the Devonian sedimentation in the south and west. The negative area by this time had shifted

[1] W. N. Benson, *Proc. Linn. Soc. N.S. Wales*, 1913, pp. 490–517.

to the position mentioned above, and such a zone of weakness appears to mark the boundary of two geological provinces in Eastern Australia. Benson has shown that in this heavy area the Devonian and Carboniferous accumulated conformably, none of the series apparently being folded until the close of the Carboniferous. Carboniferous sediments are believed by some geologists to exist in Australia south of this zone, but Mr. W. S. Dun, in a personal communication, has informed the writer that in his opinion the fossils from such sediments are to be referred to the Devonian rather than to the Carboniferous.

It is advisable, at this stage, to consider the general scheme of folding for the Devonian in Eastern Australia, inasmuch as what obtains for the Devonian in a general way, as regards its structure, is true also of the Silurian and the Permo-Carboniferous with this difference, that the analogies of form in rocks of the various periods considered are to be sought in areas which succeed each other to the north-northeast approximately in succession of time. Thus if the Silurian has been folded strongly over a large area, it may be found that the strongest folding of Devonian might be expected to be found north and east of the southern Silurian folds, whereas in certain areas of the strongest Silurian folding the Devonian is to be found bedded almost horizontally.

Thus in Tasmania the Devonian is missing; in Victoria it is folded, apparently in two series separated by an unconformity; in Eastern New South Wales it is strongly folded, whereas in Western New South Wales it occurs as a series of gentle rolls and folds, with small areas, however, exhibiting local nipping or sharp folding within the complex basement of Cambro-Ordovician and Silurian.[1] Reference to forms very similar will be made in the chapter dealing with the Permo-Carboniferous.

It may be mentioned here that a peculiar occurrence of so-called Devonian sediments has been recorded from Northwestern Australia by H. V. Woodward.[2] This observer mentions Devonian

[1] E. C. Andrews, "Canbelego Gold and Copper Field," *Mineral Resources, No. 18, Dept. Mines, N.S. Wales.* See maps and sections.

[2] *Report on Gold Fields of the Kimberley District* (by Authority), Perth, 1891, p. 10. Quoted from T. W. E. David's "Presidential Address," *Proc. Linn. Soc. N.S. Wales*, 1893.

sediments at Kimberley (Northwestern Australia), which are said to possess a strike almost northeast and southwest, and a dip of 70°, while so-called Carboniferous sediments lying immediately above are almost horizontal.

Carboniferous.—Benson's great contribution concerning the conformability of the Carboniferous with the Devonian in Northeastern New South Wales allows us to infer that the Devonian south of lat. 33° S. was folded prior to the tilting of the New England Devonian, and it suggests also that not only Middle Devonian but also Upper Devonian is to be expected in this New England series.

Permo-Carboniferous.—The Permo-Carboniferous period was a most interesting one in Australia, but only the salient points dealing with its history are here recorded so far as they deal with the main thesis of this report.

A great period of submergence is indicated over wide areas throughout peripheral Australia, but the strong folding to which certain sediments of this age were subjected at the close of the sedimentation was confined to a relatively narrow area within Eastern Australia north of the Hunter River, lat. 33° S. Thus the sediments of this age in Tasmania and Western Australia are almost horizontal; in Victoria they appear to be flexed only in the neighborhood of Tertiary faults or monoclinal folds; in Southeastern New South Wales they exhibit corrugations scarcely recognizable;[1] in the coastal region 100 miles north of Sydney they are moderately domed,[2] whereas to the west and southwest they are almost horizontal.[3] In Northeastern New South Wales, as shown by Carne, Woolnough, and the writer, the Permo-Carboniferous sediments are much folded and intruded by granite, whereas at a distance of 200 miles to the west the strata lie almost flat. In Southern Queensland the Permo-Carboniferous is intensely folded, as mentioned elsewhere in this report.

[1] E. C. Andrews, "Yalwal Gold Field," *Mineral Resources No. 9, Dept. Mines, N.S. Wales*, 1901; L. F. Harper, "The Southern Coal Field," *Memoir No. 7, Dept. Mines, N.S. Wales*, 1916.

[2] T. W. E. David, "The Hunter River Coal Measures," *Memoir No. 4, Dept. Mines, N.S. Wales*, 1907.

[3] J. E. Carne, "Western Coal Fields," *Memoir No. 6, Dept. Mines, N.S. Wales*, 1908.

Farther north, as, for example, at Gympie[1] and Mount Morgan,[2] the sediments are strongly folded and are Permo-Carboniferous in age. Along the north coastal area of Queensland there is a very long belt of sediments which are highly contorted and which appear to be Permo-Carboniferous.[3] Nevertheless, less than 100 miles inland the Permo-Carboniferous[4] dips at an angle of 12° only. All this indicates that the close of the Permo-Carboniferous period was accompanied by a strong folding movement in areas north and slightly east of the areas affected by the great closing Carboniferous movement in New England. Additional evidence of this is adduced when dealing with the regions of ore deposition in Australia.

The strikes of these foldings may be considered as subparallel to the Carboniferous lines of Benson, namely, northwest to north-northwest.

It may be pointed out here also that the area of Permo-Carboniferous sediments in Tasmania, South Australia, and Western Australia is very large; nevertheless the beds there are horizontally bedded.

Trias-Jura.—In this period there appears to have been a tendency for the old heavy, or negative, area of Central-Eastern Australia to sag again, or for the long zone of weakness separating New England from the land to the west and south to be broadened. In the northeastern portion of New South Wales and in Southern Queensland another area of sagging received a great thickness of Trias-Jura sediments.

The geographical conditions under which the two sets of sediment were deposited differed in certain well-marked features. This

[1] Jack and Etheridge, *Geology of Queensland* (by Authority), 1892, pp. 72–84. B. Dunstan has also produced detailed geological maps of this area in a late number of the *Queensland Survey Publications.*

[2] Jack and Etheridge, *Geology of Queensland*, p. 598.

[3] Lionel C. Ball, "Wolfram, Molybdenite, and Bismuth at Bamford, Northern Queensland," *Queensland Mining Journal*, 1914, p. 568. Mr. Ball has made a more definite statement as to the Permo-Carboniferous age of the beds in this district in a recent communication to the writer.

[4] J. H. Reid, "Permo-Carboniferous at Bett's Creek," *Queensland Government Mining Journal*, July, 1914, pp. 408–12.

has been indicated most clearly by Carne,[1] who calls attention to the fact that massive conglomerates, coal seams, and abundant fossil trees characterize the northern sediments as to their lower members, while tuffs and sandstones without heavy conglomerates, coal seams, or abundant tree stems characterized the southern and western sedimentation (Triassic). Cross-bedded sandstones of warm-brown color and intercalated black shales characterize the southern, middle, or Hawkesbury series, while cross-bedded sandstones are very common in the northern or Clarence series. In both series the later stages of the Trias-Jura appear to be dark shales in the main.

It is possible that the great folding at the close of the Carboniferous in Northeastern New South Wales was responsible, in great measure, for the heavy conglomerates of the Clarence series as well as of the Triassic of the Upper Hunter valley, and it is probable that very high land barriers separated the two sinking areas during a moderate part, at least, of the period. This might be expected to have caused variations in local floras. As an example, the Clarence series contains a characteristic fossil, namely, *Taeniopteris Daintreei*, whereas it is absent from the Hawkesbury. On the other hand, however, *Taeniopteris Daintreei* is found in the Victoria Trias-Jura, so that Carne and others consider the Clarence to be of different age from that of the Hawkesbury.

The southern or Hawkesbury (Triassic) area does not appear to have been dominated to the west and south by high land, inasmuch as the adjacent and subjacent Permo-Carboniferous in those directions does not appear to have been disturbed except by a gentle movement of sagging. The earlier period of the Trias-Jura appears to have been one of moderate to fair precipitation, but the middle period appears to have been subarid. In the Sydney district massive cross-bedded sandstones predominate in these middle beds, with relatively thin layers of dark-gray shales. In places layers of grit and subangular pebbles are interspersed with large blocks of these dark-gray shales, all mixed confusedly, apparently marking

[1] J. E. Carne, "Western Coal Field," *Memoir No. 6, Geol. Survey, N.S. Wales*, 1907, pp. 26–41; see also E. F. Pittman, *Ann. Report N.S. Wales*, 1880, p. 244. Quoted by Carne, *op. cit.*, p. 26.

periods of short-lived floods (sheet floods) which broke up the clays and mixed them with the pebbles and grits carried downstream by the local cloud-bursts or heavy rains. This appears also to have been the opinion of Professor H. E. Gregory, of Yale, from an examination by him in 1916 of the Sydney and Blue Mountain exposures. The upper portion of the period appears to have been one of greater precipitation in which actual lakes were in existence.

At Sydney, and a little south of that area, the Triassic beds dip inland at a very gentle angle, but, as Carne has shown, the whole southern area of these sediments has a dip averaging only from 1° to 2°. In the northeastern part of New South Wales, however, the Mesozoic coal measures and the conglomerates dip from 10° to 20°, while in Southern Queensland they have been still more disturbed. In the western portions of Eastern Australia, however, as also in Western Australia, they lie practically horizontal.

There appears to be no consensus of opinion among Australian geologists as to the origin of the Hawkesbury beds. Rev. J. E. Tenison Woods considered them to be of wind-blown origin[1] with lakes and swamps between the dunes.

In an unpublished paper R. S. Bonny considers them to be of estuarine origin. On the whole they may be said to be continental in origin, being formed in a sinking area mainly by water strains in a rather dry period.

Cretaceous.—The Cretaceous period marked a spilling over of the ocean with the formation of great epicontinental seas, especially during the Upper Cretaceous period. The area most affected was the northern portion of the old heavy area separating Eastern and Western Australia. It is probable that, during the Upper Cretaceous, the epicontinental sea extended from the Gulf of Carpentaria to the Southern Ocean. The eastern area occupied by the Triassic sediments, however, consisted of dry land during the Cretaceous. At the close of the period the whole center of Australia appears to have been raised to a moderate height above sea-level. Dunstan and Richards have recorded pronounced folding (40°–55°)

[1] "The Hawkesbury Sandstone," *Proc. Jour. Roy. Soc. N.S. Wales*, XVI (1882), 53–90.

of Lower Cretaceous rocks on the coast of Queensland at some distance north of Brisbane.[1]

Reference will be made later to this local evidence of folded Trias-Jura and Cretaceous rocks along the coast of Central and Northern Queensland.

Tertiary period.—The Eocene sea was not large and appears to have been confined to areas, relatively small, in the north and south of the continent. Indeed, the continent as a whole, except in the northeast, appears to have been growing in size subsequently to the close of the Cretaceous, although a submergence, postdating the recent Glacial period, appears to have isolated New Guinea and Tasmania from the mainland.

It is as if there has been a general tendency in Australasia and New Zealand to move in a vertical direction in post-Cretaceous time, the movement being subject to two great laws:

1. That elevation, or vertical movement, of the land was emphasized in an easterly direction, as from Western Australia to New Zealand, due allowance being made for the lagging behind differentially of the two great and relatively heavy portions, namely, Central Australia and the suboceanic mass separating Australia from New Zealand.

2. That the uplifts after the widespread peneplanation of the Cretaceous period did not proceed continuously, but were saltatory in their action, and, moreover, that the periods of time separating these uplifts became less as the present time approached, and that, nevertheless, the amounts of individual uplifts became greater as the periods marking the pauses between the uplifts became less in duration. This has given rise to great "valley-in-valley" structures owing to the interrupted work of the streams.

Thus in Australia, during what appears to be the Cretaceous period, great peneplains were formed in the land areas lying east and west of the Cretaceous sea, and only the hardest rock structures remained to show the existence of former plateaus or hills. In the various Tertiary divisions of time the streams carved valleys with

[1] B. Dunstan, *Queensland Government Mining Journal*, December, 1912; H. C. Richards, "The Cretaceous Rocks of Woody Island," *Queensland Aust. Assoc. Adv. Sci.*, Melbourne meeting, 1913, pp. 719–88.

widths so great as to appear as local peneplains, although they are only very broad, shallow valleys in whose bases other broad and shallow valleys have been excavated. The great uplifts of the later Kosciusko period allowed the streams to form profound canyons which receded along these older shallow valleys. In other words, the main Tertiary land history has consisted of repeated elevations with stream revivals. During one or more of the Tertiary divisions of time, particularly in what may be the Miocene, the land appears to have sunk with the formation of lakelike expanses along the stream courses and the burial, later, of deep-river deposits beneath basalt floods covering thousands of square miles in Eastern Australia. This led to great modifications in the stream drainage, but the dominating lesson of the repeated revival of stream action must not be overlooked, the modifications due to lava floods being only an incident in the great geographical unity of Australia in Tertiary and post-Tertiary times.

New Guinea.—If attention be turned, however, to the northeastern part of Australia, it will be found that as geological time progressed, the area occupied now in part by New Guinea was built to the south and west. An excellent epitome of the main features of structure known to date has been supplied by Professor T. W. E. David.[1] Schists outcrop at very high altitudes along its northern portion, while strongly folded Cretaceous Strata are reported to occur at the highest altitudes in the north, their steep dips ending abruptly against a high and deeply dissected plateau surface. For 50 or 60 miles inland from the south, the area consists of middle and late Tertiary strata, all intensely folded, and all beveled off by a high plain, probably one of submarine erosion. The knowledge of this strong orogenic movement in late or closing Tertiary time and the excavation of a plain of erosion within folded sediments of this age was established by Carne while doing pioneering work in the oil industry.[2]

[1] "Geology of Papua" (Federal Handbook), *Brit. Assoc. Adv. Sci.*, Australian meeting, 1914, pp. 316–25.

[2] J. E. Carne, *Bull. of the Territory of Papua, No. 1*, Dept. External Affairs, Melbourne, 1913, pp. 19–29.

David's conclusion is:

In regard to the broad tectonic features of Papua it may be suggested, very tentatively, that the mainland of Australia has functioned as a "foreland massif," Torres Straits, the Gulf of Carpentaria, the Arafura Sea, and the deep Mesozoic and Tertiary basins with their thick strata as a *Senkungsfeld*. Possibly the crystalline schists forming a great part of the backbone of the island have played the part of an inner, or *rück-land* massif which has helped to roll up the Mesozoic and Tertiary sediments.[1]

In passing, it may be mentioned that this simply raises the question again as to the origin of the forces of crumpling. Do they act from the land as suggested by Suess in his discussion of the Asiatic framework, or do they act from the oceans? If the movements be assumed to act as from Central Australia toward the oceans, then it is difficult to understand the stability and rigidity of such central area of force. If the source of energy is suboceanic and directed toward the continents, then it is difficult to explain the growth of Australia north and east, while that of New Guinea appears to be south and west, unless, indeed, it be assumed gratuitously that the later foldings in Northeastern Australia are simply the expressions of orogenic movements dying away in a southwesterly direction from the Pacific. Even so the intense contortions evidenced in the Miocene and Pliocene beds might be expected on the northeastern aspect of New Guinea rather than on the south and southwestern. It would seem, indeed, as though each negative or heavy area had played a part in the movements.

New Caledonia.—In New Caledonia the Mesozoic sediments have been intensely folded, especially on the western and southwestern aspects, and the overfolding appears to have been directed toward Australia, according to Peletan, Depiet, Piroutet, and others as quoted by Suess.[2]

New Zealand.—In turning to a consideration of New Zealand we meet with a certain amount of disappointment, inasmuch as there is no consensus of opinion among the workers on certain fundamental points. Thus a glance at Dr. J. W. Gregory's map in the article on New Zealand in the eleventh edition of the *Encyclopaedia*

[1] T. W. E. David, "Geology of Papua," *op. cit.*, pp. 324–25.

[2] *Die Antlitze der Erde* (Eng. tr.), IV, 314–15.

Britannica suggests that this island group was built principally as from southwest to east and north, or at any rate that with the progress of geological time folding movements retreated to the north by east. Marshall, however, in a personal communication, under date of April, 1916, states that much of the New Zealand Jurassic has been confused with the Maitai (so-called Carboniferous) by older workers. Marshall, however, adduces sound reasons for considering New Zealand as being the true boundary of the Pacific Ocean[1] in that portion of its area. Cotton in a recent paper states that the "most profound deformation of this vast sedimentary group [Paleozoic and Mesozoic] took place in Later Jurassic or Early Cretaceous times."[2] He also states that the average trend of the strike of this older mass appears to be west of north (p. 245). And again he writes: "It is apparent that during the period of their deposition [that is, the Tertiary Andes] a great part of the site of the present islands of New Zealand was continually submerged" (p. 247).

Cotton also speaks of orogenic movements in the Pliocene in the northern and more eastern portion of the group, and it is known, moreover, that great volcanic activity has taken place in the northeastern portion of the group with the formation of important gold deposits.

In a personal communication dated August 22, 1916, Cotton writes:

> The early geological history [of New Zealand] is much obscured by the later happenings—a great deal more so, it would appear, than is that of Australia. We cannot even be sure that we have any considerable area of Paleozoic rocks. The small areas of Ordovician and Silurian in northern Nelson we can be certain of, but we know nothing whatever of the relations of these, either to each other or to rocks of later Paleozoic or Mesozoic age. It is the opinion of the present director of the Geological Survey that the greywacke rocks extending southward along the West Coast are of Aorere (Ordovician) age; but they contain no paleontological evidence of age and are part of the "Maitai" system of other writers. As for the "Maitai" rocks throughout

[1] P. Marshall, "Presidential Address," *Geological Section Aust. Assoc. Adv. Sci. Sydney*, XIII (1911), 90–99.

[2] "The Structure and Later Geological History of New Zealand," *Geol. Mag. London*, No. 624, June, 1916.

New Zealand, there seems to be no reason now for classing them as Paleozoic. As regards the Manapouri rocks of southwestern Otago, they may, of course (with the exception of some intrusives), be very ancient; but their relations to other systems are absolutely unknown. It may be that this is an upfaulted block from which a Mesozoic cover has been removed. So far as I know there is no evidence of later formations having been folded against it.

The remarkable flat-lying schists of central and eastern Otago are, again, of indefinite age. Marshall regards them as metamorphosed Mesozoics. He traces a transition to the unaltered "Maitais," but in eastern Otago, along the junction of the schist and greywacke rocks there is a complex of faulted blocks (greywacke now forming the surface in some and schist in others) which had, there can be no doubt, been planed down before the deposition of what I call the "covering strata." Later faults, which affect the cover also, have sometimes followed the lines of the older breaks, *but have reversed the throw*.

As to the direction of folding in New Zealand I have formed no opinion. The latest or Kaikoura folding was accompanied by the formation of great reverse faults in the northeastern part of the South Island, and these hade to the northwest. Many small reverse faults in the Wellington neighbourhood, which intersect (?) Triassic rocks and were *perhaps* developed during the Mesozoic period, hade in the same direction.

One question of great importance is that of the source of the enormously thick "Maitai" sediments, which consist, from end to end of New Zealand, almost universally of the little-worn detritus from acid igneous rocks. Evidently these deposits accumulated not far from a great land mass, but I know of no evidence as to the position of that land mass. Apparently the New Zealand area sometimes formed a part of the continent, for at a number of places there are deposits containing Mesozoic plants.

So far as I know there was no strong folding accompanying the formation of the Hauraki gold deposits, but there have been considerable "block" movements since.

EVIDENCE OF THE ORE DEPOSITION

It is proposed here to see what light may be thrown on the possible structural relations or differences of Australasia, New Guinea, and New Zealand, by a study of the peculiarities of ore deposition in certain areas within these regions. In this connection it is proposed to deal principally with one set of minerals only, namely, the tin group, although conclusions equally interesting would have been forthcoming from a consideration of the gold and copper, together with the silver-lead and zinc groups.

Thus with regard to gold it would have been possible to elaborate with a wealth of detail the knowledge that the gold deposits of

West Australia are found in the great area of pre-Cambrian rocks there developed, and, moreover, that they occur in belts arranged more or less parallel and relatively narrow in width, although in certain localities they appear as small isolated areas or patches; that these narrow and well-defined belts have a general northwest and southeast direction, with divergences in certain instances of several degrees on either side of this direction; that the ore deposits in these belts or zones, owing to certain activities, do not crop out in long and unbroken lines, but are cut up into relatively short lenticles, arranged *en echelon*.

Table I gives the approximate values of the several metals mined in these countries.

TABLE I

APPROXIMATE TOTAL VALUES, IN MILLIONS OF POUNDS STERLING, OF THE MORE IMPORTANT METALS MINED IN AUSTRALASIA AND NEW ZEALAND

	Gold	Copper	Silver-lead	Zinc	Tin	Wolfram	Bismuth	Molybdenite
West Australia..	73.00	11.00	....	....	1.00	....	....	....
North Territory.	2.10	0.20	....	....	0.33	0.04	....	....
South Australia.	1.00	30.00	0.33	....	....	....	....	....
Tasmania.......	7.50	11.50	6.50	....	12.00	0.05	0.02	....
Victoria.........	300.00	0.25	0.006	....	0.80	0.005	....	....
New South Wales........	62.00	13.50	74.00	12.00	10.50	0.25	0.166	0.10
Queensland.....	80.00	11.50	2.25	....	8.50	0.80	0.125	0.25
New Zealand....	85.00	0.02	....	....	....	....	....	....

The general direction of these auriferous belts almost everywhere coincides with the strikes of the schists, which, with one or two exceptions, invariably form the matrices of the gold-bearing reefs. . . . . The quartz reefs are of two distinct types, namely, white quartz reefs and laminated quartz and jasper veins approaching very closely the hæmatite-bearing quartzites which invariably form a conspicuous feature in most of the gold fields of the State. Some of the laminated quartz veins range from almost-pure quartz, through banded jaspers, with crystals of magnetite, to bands appearing to the eye to be virtually pure haematite. The quartz reefs, of what may be called the massive types, occur plentifully in both the schists and the granites.[1]

Like the gold deposits of Western Australia those of the Northern Territory and of South Australia appear to be pre-Cambrian

[1] A. Gibb Maitland, "Mining Fields of Australia" (Federal Handbook), *Brit. Assoc. Adv. Sci.*, Australian meeting, 1914, pp. 447–48.

in age, although there are certain indications of relative youth in the gold deposits of the Northern Territory and South Australia. Eastward, in the old trough lying within New South Wales and Victoria, now filled with Cambro-Ordovician and infolded Silurian sediments, occur the most important gold deposits of Australasia, especially the famous saddle reefs of Bendigo, Ballarat, Canbelego, and other localities. Immediately to the east and north lie the ore deposits beyond the Hunter zone of weakness where Benson's line of serpentine occurs with its gold deposits of Carboniferous age. Beyond, but parallel, or subparallel, with these, are the great gold fields of the closing Paleozoic period in New England and Eastern Queensland, as, for example, at Hillgrove, Gympie, Mount Morgan, and the Palmer. It might be mentioned that, although no gold deposits appear to have been formed in Australia since that momentous period, nevertheless the important gold deposits of the North Island of New Zealand are of *late Tertiary age.* It might be mentioned here that the gold deposits of Southwestern New Zealand appear to occur in Paleozoic rocks.

Or it would have been interesting to enlarge upon the facts connected with the copper deposits of Australia: how in the west they are of pre-Cambrian age, according to Maitland and his geological staff; how the nature of the deposits there suggests deposition at a great depth below the old land surface; how the copper deposits of great but of unknown age, in the Northern Territory, South Australia, Western New South Wales, and Tasmania, as, for example, at Wallaroo, Moonta, Burra Burra, Cobar, Nymagee, and Mount Lyell, do not appear to be dependent upon ordinary igneous rock types, but, from an examination of the reports of Ward, Jack, J. W. Gregory, and the writer, they appear to be the equivalents themselves of igneous rocks because of their peculiar mineral assemblages; how with these famous deposits might be mentioned the great Broken Hill deposit of silver-lead and zinc which is apparently a replacement of schists by garnet, rhodonite, feldspar, and sulphides, owing to the action of vapors arising along a shear zone;[1] how the arrangement *en echelon* of these metalliferous areas and the individual ore lenses within such areas must be sig-

[1] E. C. Andrews, "Broken Hill Lode," *Economic Geology*, October, 1908, pp. 643–45.

nificant in the extreme. It would be instructive also to tell how, in New England, the copper and the gold which were introduced during the Carboniferous folding of Benson occur in the same deposits as a rule, as also do those of the closing Paleozoic both in New England and in the more coastal portions of Eastern Queensland (examples, Drake and Mount Morgan); how also in the Carboniferous of New England the copper and gold depend upon the serpentine belt for their existence, whereas in the Permo-Carboniferous they are related to lamprophyric dykes and basic granitic types.

In New Guinea the copper deposits appear to be in very ancient rocks, whereas in New Zealand copper is practically absent.

The tin group of minerals.—Turning, however, from these interesting points to the tin-wolfram–molybdenite-bismuth group of minerals in Australia, it may be noted that all four may occur together in certain ore deposits in this continent, but as a rule the deposits of commercial importance may be classed under two main heads. Thus tin is frequently associated with wolfram, whereas molybdenite is associated with bismuth. Should molybdenite and bismuth be associated with other minerals of the group, the preference is for wolfram rather than for tin. Indeed, the minerals associated with tin and wolfram, such as tourmaline, topaz, beryl, and quartz with rutile, are practically unknown to the writer in connection with molybdenite deposits.

All these minerals in Australia—tin, wolfram, molybdenite, and bismuth—are associated with siliceous granites or their equivalents. In New South Wales the typical tin-wolfram granites range from 75 to 79 per cent silica, while the typical molybdenite-bismuth types range from 72 to 74 per cent silica. These various granites may be distinguished easily by their peculiar vegetation, and appear to have been the hosts of the tin-molybdenite minerals in Australasia. The vapors which conveyed the minerals of the tin group to the marginal portions of the granites, preferably the roofs, or upper and lateral portions, appear to have varied in their power of penetration. Thus the tin and wolfram deposits, with their boric and fluoric associates, are found in many places at slight distances from the siliceous granites themselves, in rocks such as slate, basic igneous rock, or quartz-porphyry. Always, however,

the tin minerals may be seen to be intimately related to the siliceous granites. The molybdenite deposits are almost always within the marginal development of the siliceous granites, while tourmaline, topaz, and allied minerals are characteristically absent. Contact deposits of molybdenite in Australia, as, for instance, at Yetholme (New South Wales), are rare.

Although these granites in Australia accompanied strong folding movements, and although ore deposits in that continent appear to have been dependent upon strong folding phenomena, nevertheless it must not be inferred that all periods of folding in Australasia have been associated with the formation of ore deposits on a commercial scale, but simply that all ore deposits of commercial importance in Australasia are intimately related in some way to periods of folding. This statement refers, naturally, only to deposits of the metallic minerals.

a) Western Australia: The vast area of Western Australia consists, in the main, of highly altered rocks of pre-Cambrian age. These schists and allied types are intruded by siliceous granites and allied rocks, which also are considered to be pre-Cambrian in age. "The old granite rocks are traversed by many large ice-like quartz reefs. . . . . These older granite rocks . . . . form the matrices of the tin and allied deposits of the state."[1]

This mineral has been found to the extent of about 14,000 tons in Western Australia, while wolfram is subordinate in amount. Molybdenite has been recorded in small scattered flakes from this area.

b) Northern Territory: The rocks of the Northern Territory are extremely old, probably pre-Cambrian in many places. Tin and wolfram to the values respectively of £400,000 and £40,000 approximately have been won from the Northern Territory. Molybdenite has been reported, but it has not been worked as yet.

c) South Australia: The ore deposits of South Australia are very old. Tin, wolfram, and molybdenite have been found in this state, but the amounts won are too negligible to be considered.

[1] A. Gibb Maitland, "Mining Fields of Australia" (Federal Handbook), *Brit. Assoc. Adv. Sci.*, Australia meeting, 1914, pp. 446–47.

d) Tasmania: The tin, wolfram, molybdenite, and bismuth deposits of Tasmania are considered to be of closing Silurian or early Devonian age.[1]

The tin production exceeds £12,000,000 and the wolfram £50,000 in value. Molybdenite has not been worked, but bismuth to the extent of about £200,000 value has been won.

e) Victoria and Southeastern New South Wales: In Victoria the age of the tin, wolfram, molybdenite, and bismuth deposits is not known definitely. The value of the tin won is slightly less than £1,000,000, that of the wolfram about £5,000, while molybdenite and bismuth have been found only in very small quantities.

Probably Victoria and Southeastern New South Wales form one geological province, and in the latter area the tin and allied minerals may be considered as of post-Devonian and of pre-Permo-Carboniferous age. Tin is relatively rare, but molybdenite and bismuth are abundantly represented.

f) Northeastern New South Wales and Eastern Queensland: The northeastern portion of New South Wales appears to be a province geologically distinct from that of the southeastern portion of the state, and the tin, wolfram, molybdenite, and bismuth deposits found there appear to be closing Paleozoic in age. These deposits are confined to a strip less than 150 miles from the coast. The commercial molybdenite and the bismuth occur within the eastern zone, while the commercial tin occurs within the western zone. The small deposits of the far west, near Broken Hill, for example, apparently are of very early Paleozoic age, and they really belong to the South Australian region or province.

The value of the tin won from New South Wales exceeds £10,500,000, the wolfram values approximate £200,000, the bismuth £150,000, and the molybdenite about £100,000.

In this connection it should be remembered that until 1902 molybdenite was considered as an impurity in the bismuth, its

[1] W. H. Twelvetrees, "The Scamander Mineral District," *Bull. No. 9, Geol. Survey, Tasmania*, 1911, p. 23–24; other official reports of great interest dealing with the subject of mineral deposits in Tasmania are by L. K. Ward, Loftus Hills, and L. L. Waterhouse.

inseparable associate in New South Wales; thus great amounts of the molybdenite have been lost.[1]

Queensland, in its eastern portion, should be considered as belonging, probably, to the same geological province as New England, or Northeastern New South Wales.

The tin, wolfram, molybdenite, and bismuth deposits are found only within the eastern strip of the state, and their age appears to be the close of the Permo-Carboniferous. The granites and mineral associations of the two areas are almost identical also. Thus this great province of Eastern Queensland and New England, which has yielded the bulk of the world's supply of molybdenite, lies on a great flat arc having a general trend of northwest to north-northwest. These ore deposits are associated with strong movements of folding, the age of which appears to be closing Paleozoic.

The approximate values of the tin, wolfram, molybdenite, and bismuth won from Queensland are respectively £9,000,000 to £10,000,000, £1,000,000, £250,000, and £150,000.

It would thus appear that the deposits of the tin and molybdenite group of minerals in the great geological province of Western Australia, South Australia, and the Northern Territory are of great age, but that they are almost negligible in commercial value. It is not known, however, what proportion of this absence is due to removal by erosion of the upper portions of the granites. The deposits of this group in Tasmania may be of closing Silurian or early Devonian age, the tin values being very large, but wolfram, molybdenite, and bismuth are unimportant; the deposits of the geological province of Southeastern Victoria and Southeastern New South Wales are important and are post-Devonian and pre-Permo-Carboniferous in age; while the deposits of the province of New England and Eastern Queensland, forming a coastal fringe to Northeastern Australia, are highly important from a commercial point of view and appear to be closing Paleozoic in age.

[1] Official reports have been written on the tin and molybdenite areas of New South Wales by T. W. E. David, J. E. Carne, and the writer, while Professor Leo A. Cotton has published reports on the tin of New England in the *Proc. Linn. Soc. N.S. Wales* XXXIV (1909), 738–81; Cotton intends to continue the study of tin genesis in Australia in the near future.

All of these Australasian deposits are intimately related to strong movements of folding, accompanied by intrusions of very siliceous granite.

No molybdenite, bismuth, wolfram, nor tin of any commercial importance whatever appears to have been found in New Guinea, New Caledonia, or New Zealand, although molybdenite and allied minerals have been recorded as curiosities in older Paleozoic granites in New Zealand. Neither are there in New Zealand any important copper deposits similar to those which are so intimately associated with the gold, tin, and molybdenite in Australasia.

CONCLUSION

It is therefore permissible, perhaps, to infer that each of the three great groups, namely Australia, New Guinea, and New Zealand, is a distinct geological province, but whereas in New Guinea the movements appear to have opposed the Australian growth with a tendency to fill the intervening negative area; on the other hand the growth of Australasia and New Zealand appears to have been intimately related in some manner, as though each had grown sympathetically in response to some simultaneous dominating agency. The folding action ceased in the Australasian area long before it did so in the New Zealand area. The foldings in New Guinea also were maintained right into recent geological time.

Here again the ore deposits proclaim the independence of the three centers. The oil fields of New Guinea suggest the Burmese or Malaysian origin of the New Guinea lines of structure,[1] and in a similar way the tin-wolfram–molybdenite-bismuth group of minerals appears to mark the real limits of Australasia. A little of the molybdenite group occurs in the New Zealand area, in the very old rocks, but the group as a whole, with its grand suite of siliceous granite horsts, may be said to end at the east side of Australasia. Moreover, as the folding movements retreated east and west, with progress of time they appear to have passed away finally to the northeast from Southwestern Australia toward New Caledonia.

[1] T. W. E. David, "Geology of Papua" (Federal Handbook), *Brit. Assoc. Adv. Sci. Australia*, 1914, p. 320.

It is therefore permissible, perhaps, to infer that the Tasman Sea is of great age, especially in its more southern portions, inasmuch as it appears to have been a barrier to common or related ore deposition between Australasia and New Zealand through the ages.

This of course does not imply that Australasia and New Zealand have not been closer together in the past, nor that Australasia has not extended considerably farther to the east in former times, especially in its northeastern portions; it simply suggests that some great agency which controlled the growth of Australasia and New Zealand appears to have admitted a negative or relatively sunken area from early times in the region of the Tasman Sea, and that this agency had faded away to epeirogenic movements in the Australasian area while yet it was vigorously folding the New Zealand rocks.

All this appears to be in harmony with the general contention of Marshall[1] who maintains that New Zealand, and not Australia, lies on the real border of the Pacific. Marshall, however, approaches the subject from a point of view entirely different from that taken in the present note.

[1] P. Marshall, "Presidential Address," *Geological Section, Australian Assoc. Adv. Sci. Sydney*, XIII, (1911), 90–99.